

# **ROTATING EXCHANGE FLOW**

Daniel R. Ohlsen  
Colorado Research Associates  
3380 Mitchell Lane  
Boulder, CO 80301  
phone: 303-415-9701 x204 fax: 303-415-9702 email: Daniel.Ohlsen@colorado.edu

John E. Hart  
Program in Atmospheric and Oceanic Sciences  
Campus Box 311  
University of Colorado  
Boulder, CO 80309-0311  
phone: 303-492-8568 fax: 303-492-3524 email: hart@tack.colorado.edu

Award # N00014-94-1-0020 and N00014-97-0-0151

## **LONG-TERM GOALS**

Flow through ocean straits and channels helps set the water-mass properties of the larger basins at each end. The long term goal of this research is an understanding of the roles that rotation and friction play in the transport and water mass mixing of flows through oceanic straits, channels and canyons.

## **OBJECTIVES**

The influence of planetary rotation on exchange flow is studied. The Coriolis force and either boundary friction or interfacial friction (for the case of layered exchange flows) drive cross-channel secondary circulations. The short term goals of this study are to understand the dynamics of these circulations and especially their influence on interfacial mixing in and transport through straits.

## **APPROACH**

Laboratory and numerical models are utilized. Both two-layer, hydraulically driven and continuously stratified, thermally driven flows are studied with laboratory experiments. A 2-1/2 dimensional numerical model is also used to examine the two-layer case. The numerical model calculates density and all velocities in the cross-channel plane while assuming no variations along the channel. This model is a direct numerical simulation for laboratory scales in the y-z plane in that scales down to dissipation are resolved.

One laboratory set-up consists of two basins joined by a tube or open-top channel through which water of different salinities is exchanged. The apparatus sits on a rotating table to simulate planetary rotation. The laser induced fluorescence technique is used to non-

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>30 SEP 1997</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1997 to 00-00-1997</b>	
4. TITLE AND SUBTITLE <b>Rotating Exchange Flow</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Colorado Research Associates,3380 Mitchell Lane,Boulder,CO,80301</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

intrusively measure the cross-channel density field for comparison with the numerical simulations. A precision micro-CTD measures salinity changes and thus transport through the channel for comparisons to the model and theory.

In the other laboratory experiment, a warmed and a cooled basin are joined by a strait, all on a rotating table. The free-surface is imaged with an infra-red camera to diagnose temperature. Velocities are observed with dye streaks and total transport is measured via injection of acid and base and transport-induced pH changes.

## **WORK COMPLETED**

An extensive parameter space search with the numerical model has found a simple empirical relation between the exchange rate and the hydraulic head, planetary rotation, and viscous input parameters. This relation is verified by the two-layer experiments over a smaller parameter range. The numerical model is further verified by comparisons to the laboratory cross-channel density field. A paper is in preparation on this work.

A shorter tube and a open-top channel have been constructed for the next set of experiments. The shorter tube was necessary to verify numerical model's prediction of the viscous dependence of the transport. The open channel will be used for the free-surface experiments.

The thermally-forced laboratory experiment has been rebuilt with thymol blue dye wires added for visualization along with dams for each reservoir. The dams allow transport measurements using acid/base pH measurements in each reservoir before and after each run much like the salt measurements in the hydraulic experiments.

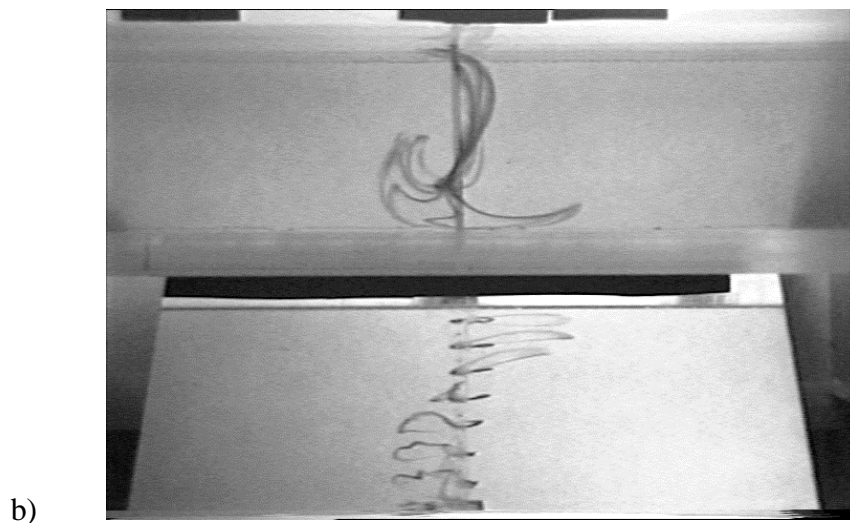
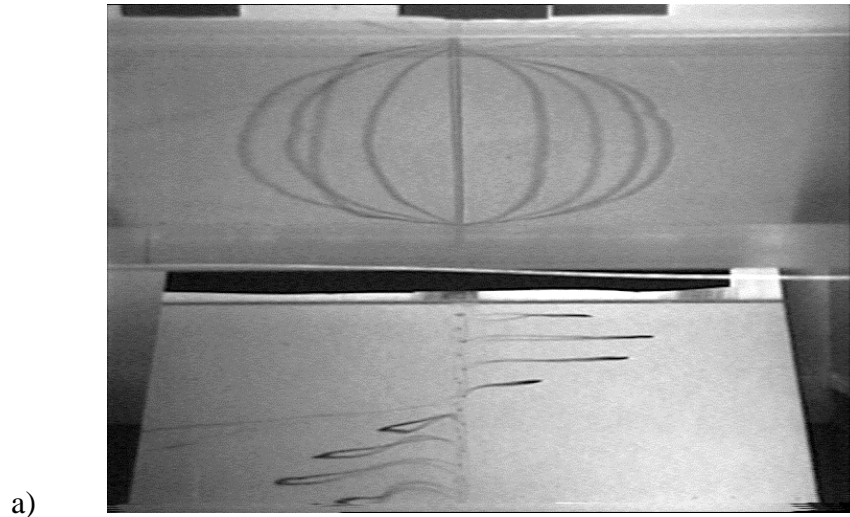
## **RESULTS**

Planetary rotation reduces the transport in two-layer flow down a strait. The inclusion of side-wall and interfacial friction and mixing gives a much smaller predicted transport than inviscid theory unless rotational effects are very large. The experiments verify the frictional and Coriolis dependence of the numerically predicted transport. In addition, the presence of even weak cross-channel circulations enhances the production of intermediate property fluid by mixing between the two layers. This intermediate fluid is directly advected away from the interface by the secondary circulation rather than just diffused by turbulent mixing as in the nonrotating case.

The thymol blue dye visualization in the thermally-forced experiments demonstrate the flow changes with rotation very clearly. In Figure 1 the channel is viewed from above in the top half of each picture and from the side (with the channel top at the bottom in the picture) in the bottom half. The left end of the channel is cooled and the right heated. With large rotation, the flow is no longer down the channel but meanders in baroclinic waves. The transport in this flow is much reduced compared to the non-rotating case.

## IMPACTS/APPLICATIONS

The increased vertical mixing which planetary rotation forces in exchange flows is important to boundary condition parameterizations in numerical models of basin or global scale numerical ocean models. Similarly, the thermally-driven experiments should expand the oceanic applicability of this study, since this generalizes the two-layer version to continuous stratification. In addition, we explicitly target the entire linked basin/strait system, including the convecting basin, the exchange flow through the strait, and the mixing and entrainment of the convecting fluid as it enters and exits the strait.



c)

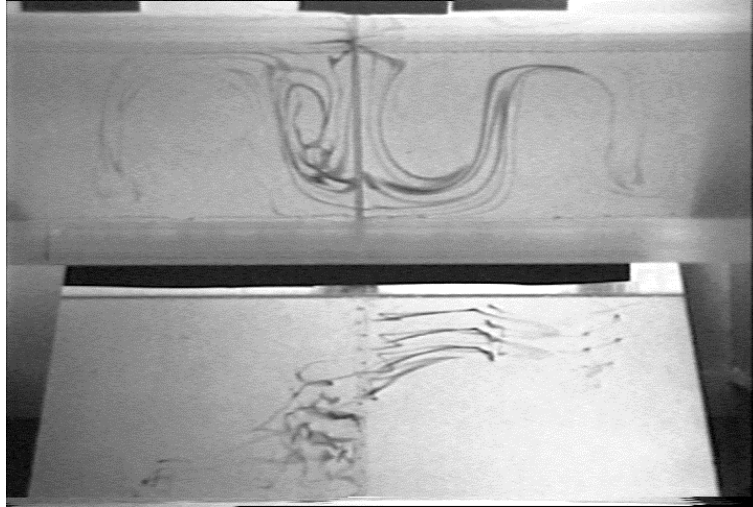


Figure 1: Top and vertically flipped side views of thermally forced rotating strait experiments. The dark lines are dye generated at the center wires. a) no rotation, b) rotation, c) same as b) but later in time.

## **TRANSITIONS**

## **RELATED PROJECTS**

## **REFERENCES**

Ohlsen, D.R. 1996: "Effect of planetary rotation on bulk transport and interfacial mixing in exchange flow through straits", presented at 1996 Amer. Physical Society Div. of Fluid Dynamics meeting, Nov. 1996, abstract in *Bull. Am. Phys. Soc.*

Ohlsen, D.R., 1997: "Rotating channel exchange. Experiments and numerics", Invited lecture given at WHOI Summer GFD Program, June, 1997.